XYRIS SPATHIFOLIA (XYRIDACEAE), A NEW XYRID FROM THE KETONA DOLOMITE-LIMESTONE GLADES OF ALABAMA

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ABSTRACT

A distinctive new *Xyris* has been found in a single small (<0.01 ha) calcareous dolomitic (Ketona Limestone) fen in Bibb County, Alabama. The novelty grows alongside the rare and endangered *X. tennesseensis*, but is consistently distinct from it. We distinguish this putative new taxon from the latter, giving it species rank based upon observations of field-collected material, greenhouse common garden trials, and herbarium surveys. The new species, **X. spathifolia** is herein described, figured, and its relationship with *X. tennesseensis* discussed.

RESUMEN

Se ha encontrado un nuevo *Xyris* en un pequeño humedal dolómitico (<0.01 ha) (caliza de Ketona) en el condado de Bibb, Alabama. Esta novedad crece junto con la rara y amenazada *X. tennesseensis*, pero es distinta de ella. Distinguimos esta nuevo taxon putativo, dándole el rango de especie basándonos en observaciones de material recogido en el campo, pruebas realizadas en invernadero, y revisiones de herbario. Se describe aquí la nueva especie, **X. spathifolia,** se ilustra, y se discute su relación con *X. tennesseensis*.

INTRODUCTION

Despite the pervasive notion that cataloging of the vascular plant flora of North America is complete, new species continue to be discovered. Frequently, these discoveries occur in spatial or temporal clusters, revealing a botanical "hot spot," as in the case of the Ketona Glades of Bibb County, Alabama (Ertter 2000), located at the extreme southern edge of the Ridge and Valley Ecoregion (Fig. 1). During the last 10–12 years, nine vascular plant taxa new to science (including the one described herein) have been identified from this area, as well as seven state records including some regional disjuncts, and more than 60 taxa of conservation concern (Allison 2001). With a total flora of over 420 species occurring within an area of ca. 125 ha (Alabama Water Watch 2002), it is one of the most botanically diverse areas in the eastern United States (Allison 2001).

During a 1999 field survey of populations of the rare and endangered *Xyris tennesseensis* Kral in the Ketona Glades, a markedly different xyrid, shorter in stature and smaller in vegetative and floral features, was found admixed with the former in a small, intermittent seep at the headwaters of a tributary to Alligator Creek (*M. Moffett s.n.*, 7 Aug 1999). On the date of the discovery, approximately 900 flowering spikes of the novelty were tallied, emanating from approximately 200 clumps. Individuals of the putative new xyrid showed consistent differences from *X. tennesseensis* across the mixed population. This smaller and different xyrid, thus far known only from the type locality, was once relatively abundant. However, severe drought during the summers of 1999 and 2000 decimated the population. The drastically reduced population size and fluctuating local climate have limited the collection of additional voucher material.

The site of this mixed *Xyris* population, containing the novel xyrid, is a fen/seep complex at the headwaters of Alligator Creek, within an area mapped as "Alligator Glades West" by the Alabama Natural Heritage Program (Alabama Natural Heritage Program 1999), and referred to as "Enchanted Glade" by Allison (2001). Alligator Glades West is one of ca. 45 such sites comprising the Bibb County Ketona Glades and contains the sole known population of this new taxon. The Ketona Glades are shallow-soiled, herbaceous communi-

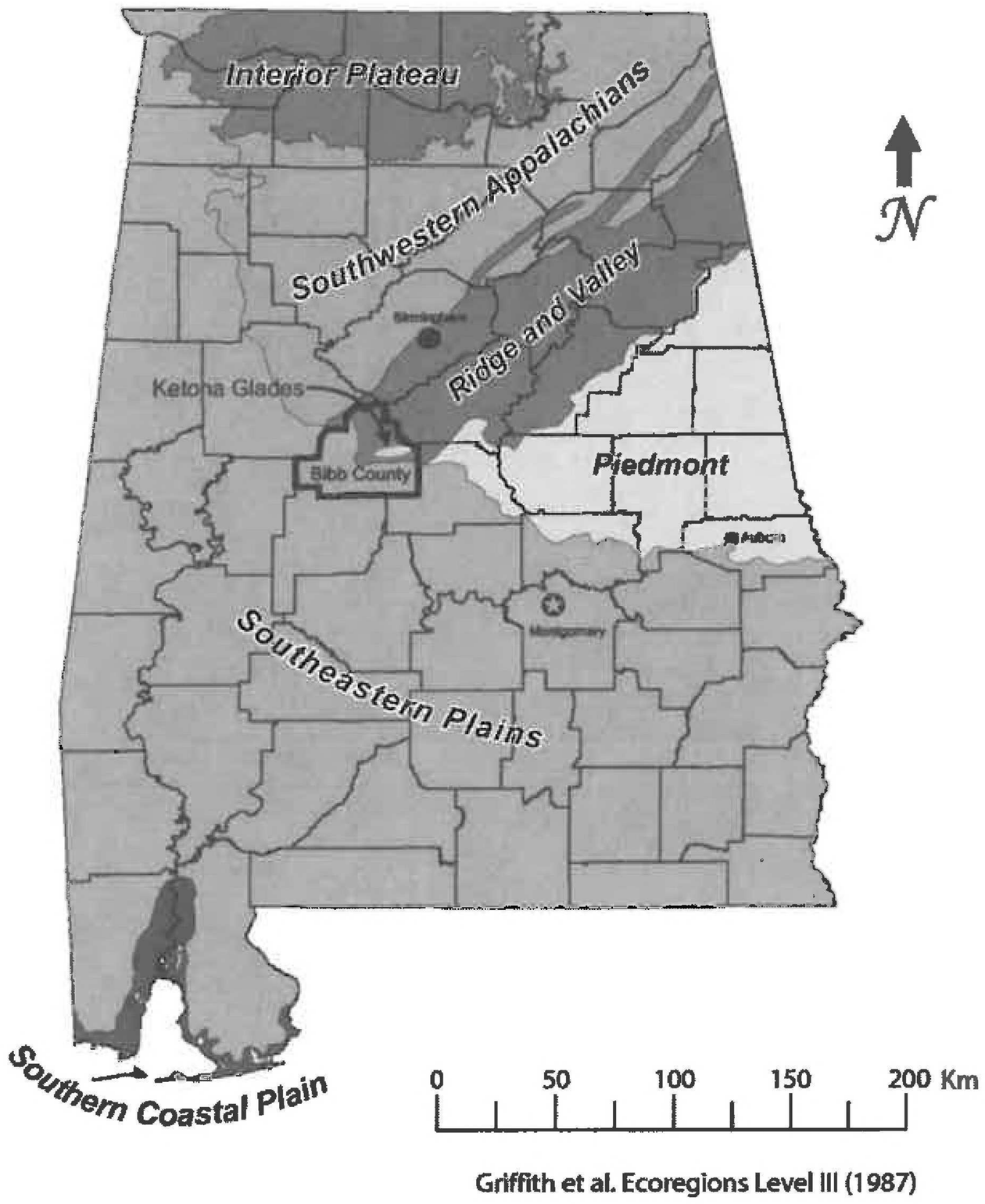

FIG. 1. Map of the study area.

ties atop outcrops of Ketona dolomite, an unusually pure dolomite (i.e., few siliceous contaminants) with relatively high levels of Mg (> 1,100 ppm). The seep itself is very small, ca. 24 m^2 (3 m × 8 m) in size. It is located 1.7 km N of Bulldog Bend (Little Cahaba River) in Bibb County, Alabama (Lat. 33° 04'; Long. 87° 01'). Ownership of this site has changed several times during our investigation. It is currently owned by Forest Investment Associates, and previously by Great Eastern Timber Company, and prior to that by U.S. Alliance/Coosa Pines Corporation, all of whom we are indebted to for access. Extensive searches made along Alligator Creek, and of the six glades (and their ecotones) in Bibb County known to contain *X. tennesseensis*, have yielded no other populations.

METHODS

Common Garden Experiment

The common garden experiment initially developed from an attempt to prevent the extinction of this interesting new taxon. During the severe summer drought of 2000, and following the severe drought in late summer and fall of 1999, there was concern regarding the future viability of this sole known population of *X. spathifolia*. In August 2000, as a hedge against possible future extirpation, a mature fruiting spike was collected from each of the 13 surviving clumps sporting at least two such spikes. A mature fruiting spike also was collected from 13 of the surviving 21 flowering clumps of *X. tennesseensis*. Spikes were stored in separate brown paper sacks in an unheated outdoor shed in Opelika, Lee County, Alabama.

In February 2001, seeds from each spike were sown onto a 60:40 mixture of Pro-Mix (Premier Horticulture, Dorval, Canada) and sand in separate 15.2 cm diameter (6-inch) clay pots and grown in a heated/evaporatively-cooled greenhouse at the Auburn University Plant Science Research Center (PSRC). Approximately 50–100 seeds germinated in each pot by June. Plants were thinned to about 10 per pot during

the second year, and their parental identity was carefully maintained. Seedlings removed from pots (and hence the experiment) were grown commingled in flat trays in a separate part of the greenhouse. Annual greenhouse temperatures typically range from ca. 18.3–29.4°C, per PSRC records. During the growing season (March to October), the average daily photosynthetic photon irradiance at bench level (adjusted for 60% shade cloth) ranged from 3 mol m-2 d-1 to 15 mol m-2 d-1, on overcast and sunny days, respectively (Elkins and Wallace 2000). Plants were fertilized every two weeks with liquid 20-20-20 (N-P-K) during the growing season. During the subsequent three years, the seedlings matured and reproduced vegetatively, generating clumps of ca. 30–40 ramets and 30–60 flowering spikes per pot by the summer of 2003.

During the summer of 2004, we realized that what began as a "rescue propagation" could provide data for a limited morphometric analysis of the principal characters distinguishing these syntopic xyrids. The 3-year-old plants of known parentage grown from seed in a common environment constituted a "common garden" experiment. Sample size was N = 25; 12 pots of *X. spathifolia* and 13 pots of *X. tennesseensis*.

The nine morphological characters selected for measurement are aspects of the new taxon that, in the field, appeared most obviously different from *X. tennesseensis*, and were also easily quantifiable. The characters are: leaf length, leaf width, plant height, spike length, lateral sepal length, petal length, anther length, stamen length, and seed length. In all cases, measurements were taken at the widest (or longest) part of a structure along the appropriate axis. With regard to plant height, the longest or "tallest" plant structure for each ramet was measured. This was usually a measure of maximum scape length, although in some cases the structure of greatest length was a leaf. Flower petal length was measured from base of claw to blade apex. Stamens were measured from the point of basal fixation with the anther to the lowest point of basal adnation to the corolla. Seeds were measured along the major axis (i.e., tip to tip). Data were not collected on several other important characters used in North American *Xyris* species classification because of the high similarity of the two taxa for these characters. Excluded characters included: keel features of the lateral sepal, position of the lateral sepal relative to the bracts (i.e., inserted/exserted), color and texture of the leaf sheath, and the presence/absence of a mealy (farinose) seed coating.

Samples were generated by first numbering all reproductive ramets in a pot, and then randomly selecting five ramets from each pot. Sample values for each pot were created by averaging the values recorded from the five randomly selected ramets. Since most of the plants resulting from the original propagation did not flower and produce seeds until summer/fall 2003, it is certain that most ramets selected for measurement in this experiment were the result of asexual, vegetative reproduction. Thus, each sample represented a mean of the progeny of a single distinct, field-identified clump. Samples for different characters were developed using different approaches.

Measurements of leaf length and width were gathered from the four outermost leaves of each selected ramet. Spike lengths were obtained using all spikes from a selected ramet. Measurements of floral structures were recorded from the single open flower on each spike (it is usually the case with *Xyris* that only one flower opens each day per spike). For seed length measurements, all mature capsules were identified on each spike and numbered. One capsule was randomly selected from each spike and then five seeds were subjectively chosen from each capsule for measurement. Plant height measurements involved but a single value for each ramet. Length measurements for petals, sepals, stamens, anthers, and seed length were made using a light microscope with a stage micrometer.

Differences in the nine character means for the two taxa were statistically analyzed using the Student's t-test, except when data violated normality assumptions and were not subsequently improved using either square root or logarithmic transformations. This was the case involving seed size, where the non-parametric Mann-Whitney U-test was employed. Normality was assessed using the Kolmogrov-Smirnov and Wilk-Shapiro tests. Homogeneity of variance assumptions were evaluated using Levene's test, with Levene's correction applied to violations. Effect sizes for t-tests are expressed as eta^2 values, and for the Mann Whitney-U test by an effect size correlation (r $\gamma\lambda$) using Cohen's D. Statistical software utilized was SPSS 16.0. Analysis adhered to procedures found in Pallant (2001) and Shannon and Davenport (2000).

Review of Herbarium Records

Xyris specimens from numerous state, regional, and national herbaria were reviewed and annotated as part of this project. Taxa selected for the review process were either part of the *X. difformis* "complex" (Kral 1978) or known to occur syntopically with *X. tennesseensis*. The *X. difformis* complex comprises *X. difformis* (varieties *curtissii*, *difformis*, and *floridana*), *X. tennesseensis*, and *X. torta*. *Xyris jupacai* is not considered a member of this complex, but does co-occur with *X. tennesseensis* at a few locations. Only those specimens collected from Alabama, Georgia and Tennessee (the tri-state range of *X. tennesseensis*) were examined. The purpose of this investigation was to determine if specimens of *X. spathifolia* had been collected previously under a different name, thereby providing not only additional specimens for study, but also expanding the known range of the new taxon. Approximately 900 specimens of *X. difformis, X. jupicai, X. tennesseensis*, and *X. torta* were examined from vascular plant collections at AUA, DUKE, GH, JSU (Jacksonville), JSU (Anniston Museum of Natural History), MO, NY, US, TROY, UNAF, HALA, UNA, FLAS, GA, MICH, NCU, TENN, and VDB at BRIT. Herbarium acronyms follow Index Herbariorum (Holmgren 2008).

RESULTS

Common Garden Experiment

Analysis of morphological characters from greenhouse grown plants in a common garden setting revealed significant differences in all nine size-related traits. In all cases, measurements for *X. tennesseensis* specimens were significantly larger than those for *X. spathifolia* (Table 1). Significance values ranged from < 0.001 to 0.03, with effect sizes indicating that 39–93% of the variance in each character was explained by taxon identity. Table 2 provides an assessment of character state differences between the two taxa based on vouchered herbarium specimens and field-collected material.

Review of Herbarium Records

Review of approximately 900 specimens of *X. difformis, X. jupicai, X. tennesseensis* and *X. torta* from 19 national, regional and state herbaria located only a single record fitting the concept of *X. spathifolia*, collected by James R. Allison in 1993 from Alligator Glades West, the sole known extant site of this new taxon.

TAXONOMIC DESCRIPTION

Xyris spathifolia Kral & Moffett, sp. nov. (**Fig. 2**). TYPE: U.S.A. ALABAMA. Bibb Co.: Alligator Glades West, small seep over Ketona Dolomite at headwaters of W branch of Alligator Creek (Lat 33° 04'; Long 87°, 01'), 7 Aug 1999, *M. Moffett s.n.* (HOLOTYPE: VDB).

Xyris spathifolia, Kral et Moffett, sp. nov., *X. tennesseensi* Kral (**Fig. 3**) simillima sed statura breviora 15–40 (non 30–70 cm) alta, laminis vaginibusque foliorum valde (non leviter) papillosis, scapis apicem versus valde 5–7-costatis (non bicostatis), caulis basi rhizomatibus brevis ascendentibus muntis (non erhizomatibus), differ.

Perennial, cespitose, 15–40(–50) cm tall, roots fibrous. Stems short, or present as slender, ascending, rhizome-like bases on innovations (result of burying of clump by seciment). Leaves ascending to erect, 15–30 cm long, soft, sheaths often fully as long as blade or longer, gradually widening from keeled apex to convex base, proximally multi-costate, smooth, pale tan to brown, upsheath with tints of red or pink, progressively increasingly papillose, densely so and green distally, margins pale, scarious, gradually narrowed to blade (this often most of its length infolding distal leaf of innovation); blade linear, mostly 1–2 mm wide, slightly to very twisted, flattened, margins proximally to medially strongly papillose, toward apex smooth or nearly so; apex narrowed, excentrically acute, its incurved tip incrassate, blunt, smooth; surfaces densely pale-granular-papillose and interruptedly rugulose proximally, progressively smoother up-blade. Scape sheaths shorter than principal leaves, mostly open, short-bladed. Scapes erect or ascending, narrowly linear, ca. 1 mm thick, twisted, pale green, proximally subterete with (mostly) 5–8 papillate costae, the intervals smooth or nearly so, distally sharply unequally angulate-ribbed, with up to 5(–7) costae making the angles, 2–3 most raised, all densely papillate-tuberculate, the intervals sulcate to broadly concave, slightly to very papillose or papillose-rugulose in short lines. Spikes ovoid to ellipsoidal or lance-ovoid, 5–8 mm long, blunt, several flowered, bracts in flat spiral, loosely imbricate, the proximal 2–3 sterile, narrowly ovate-triangular, 2.5–3 mm

TABLE 1. Comparison (mean ± SE) of nine different character states evaluated in the common garden experiment. Independent samples t-tests were used for the first eight characters. The Mann-Whitney U test was used for the ninth character (seed size). Homogeneity of variance violations and subsequent Levene's corrections are indicated by asterisks (*). Degrees-of-freedom values departing from 23 ($N_1 + N_2 - 2$) result from these corrections. A significance threshold of $\alpha = 0.05$ was used. Effect sizes for t-tests and Mann-Whitney U tests are given by eta^2 and effect size correlation ($r\ \gamma\lambda$) using Cohen's D, respectively.

Character	***X. spathifolia*** (***n*** = 12) (mean ± S.E.)	***X. tennesseensis*** (***n*** = 13) (mean ± S.E.)	d.f.	Test Statistic	Sig.	Effect Size
Leaf length (cm)	24.1 ± 1.57	48.9 ± 2.3	20.8	-8.87 *	<0.001	0.774
Leaf width (mm)	1.51 ± 0.16	6.98 ± 0.69	13.3	-7.77 *	<0.001	0.733
Plant height (cm)	27.5 ± 3.54	48.6 ± 3.83	23	-4.05	0.001	0.413
Spike length (mm)	6.75 ± 0.42	13.0 ± 0.67	19.8	-7.93 *	<0.001	0.732
Petal length (mm)	3.46 ± 0.03	4.44 ± 0.04	22.2	-17.5 *	<0.001	0.930
Sepal length (mm)	4.27 ± 0.06	4.77 ± 0.07	23	-5.59	<0.001	0.575
Stamen length (mm)	1.01 ± 0.02	2.14 ± 0.06	15.7	-17.1 *	<0.001	0.926
Anther length (mm)	0.55 ± 0.02	1.74 ± 0.07	13.8	-17.1 *	<0.001	0.927
Seed length (mm)	0.52 ± 0.01	0.55 ± 0.01	22.7	-2.18	0.03	0.39

TABLE 2. Comparison of selected morphological features in two *Xyris* taxa.

Character State	***Xyris spathifolia***	***Xyris tennesseensis***
Plant height	15–40(–50) cm	30–70(–85) cm
Stem base	May be short-ascending-rhizomatous (ascending lateral offshoots)	Lacks rhizomes
Principal leaves (length × width)	15–30 cm × 1–2 mm	40–60 cm × 4–10 mm
Leaf surfaces	Sheath papillate medially and distally, blade edges papillate, proximal surfaces papillate	Sheath smooth or finely papillate, sheath keel sometimes papillate, blade edges mostly smooth, surfaces smooth
Scapes	Subterete and multicostate proximally, ca. 1 mm wide distally, sharply 5–7 angled isodiametric, ridges densely papillate-tuberculate, some sharply raised, intervals sulcate or deeply concave, papillate	Subterete and multicostate proximally, 2–3 mm wide distally, often compressed, 3–5 ridged, with 2 ridges flattened and wing-like, all papillate at edges, intervals smooth, level to shallowly concave
Spikes	Ovoid to ellipsoidal or lanceovoid, 5–8 mm	Ovoid, 10–15 mm
Lateral sepals	4.0–4.5 mm long, lanciform, keel ascending-lacerate apically	4.5–5.0 mm long, lanciform, keel ascending-lacerate apically
Petal blades	Obovate, ca. 3.5 mm	Obovate, ca. 4.5 mm
Stamens	1–1.1 mm long, anthers 0.5–0.6 mm	2–2.4 mm long, anthers 1.5–2 mm
Seeds	Ellipsoidal, ca. 0.5 mm, slightly farinose slightly to very farinose	Ovoid to broadly ellipsoidal, ca. 0.5–0.6 mm,

long, keeled, the fertile ones broadly obovate, 4.5–5 mm long, convex, apex broadly rounded, entire, aging erose, surface a lustrous rich brown with a green, ovate, subapical, granular dorsal area. Lateral sepals free, equilateral, oblanceolate (viewed from side), ca. 4–4.5 mm long, acute, the thin keel entire proximally, progressively widening and shallowly ascending-lacerate distally. Petals distinct, blades obovate (measured from claw apex), ca. 3.5 mm long, apically erose; staminodia bibrachiate, staminodial hairs pencillate, slightly clavate. Capsule ellipsoid-cylindric, 2–2.5 mm long, placentation 3-parietal; seeds broadly ellipsoid to narrowly ovoid, ca. 0.5 mm long, apiculate, with 8–10 ribs/side, slightly farinose.

Etymology.—The epithet "*spathifolia*" is based on a peculiar morphology of lower leaves of innovations. These are spathe-like, their margins conduplicate and enfolding inner leaves.

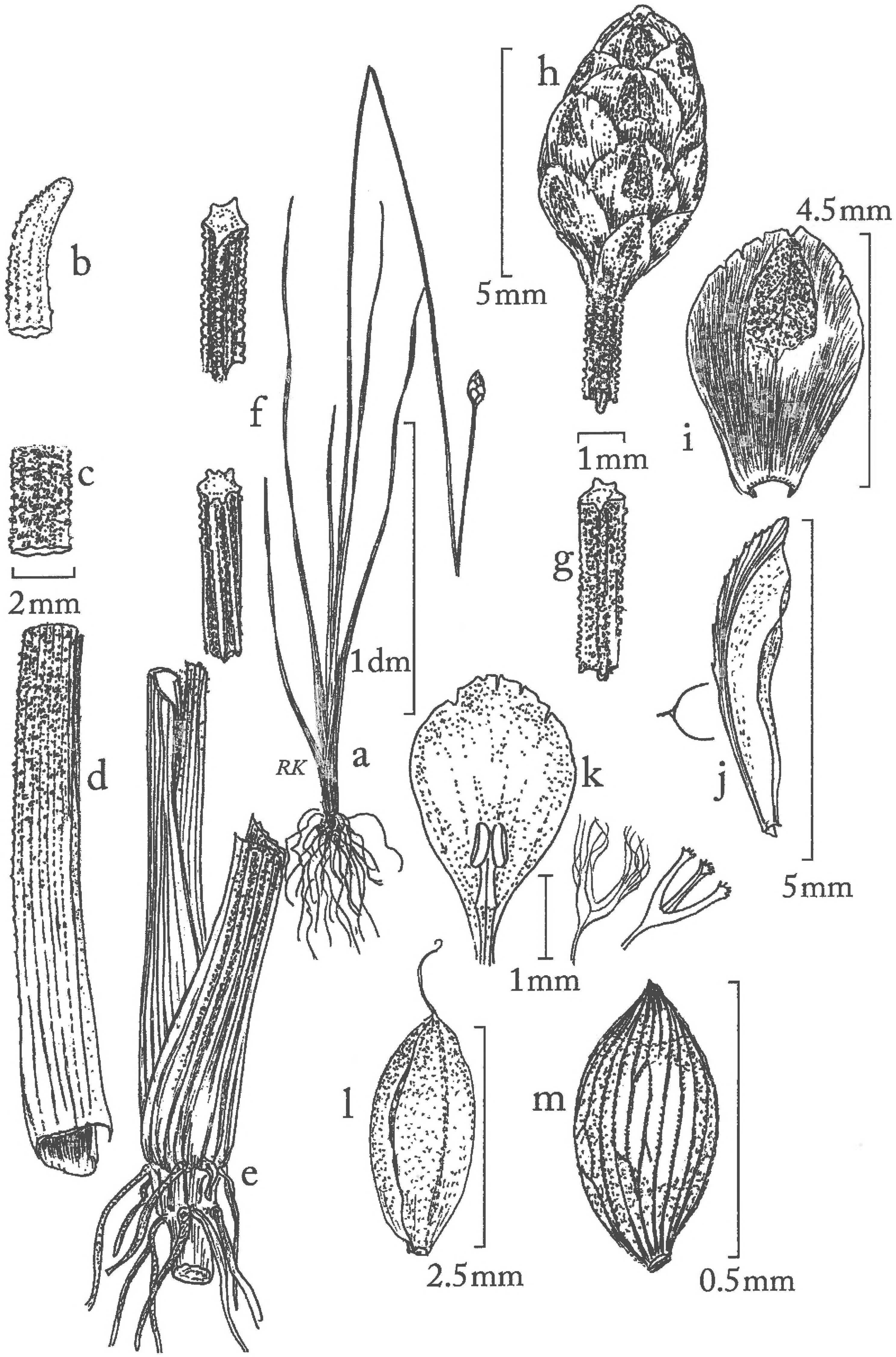

FIG. 2. *Xyris spathifolia* (from the type). a. Habitat sketch. b. Leaf tip. c. Sector of leaf midblade. d. Leaf sheath. e. Base of innovation. f. Sectors of lower (below) and middle (above) scape. g. Sector of distal part of of scape. h. Spike. i. Fertile bract. j. Lateral sepal. k. Petal blade and anther (left), staminodium and style branches (right). l. Capsule. m. Seed.

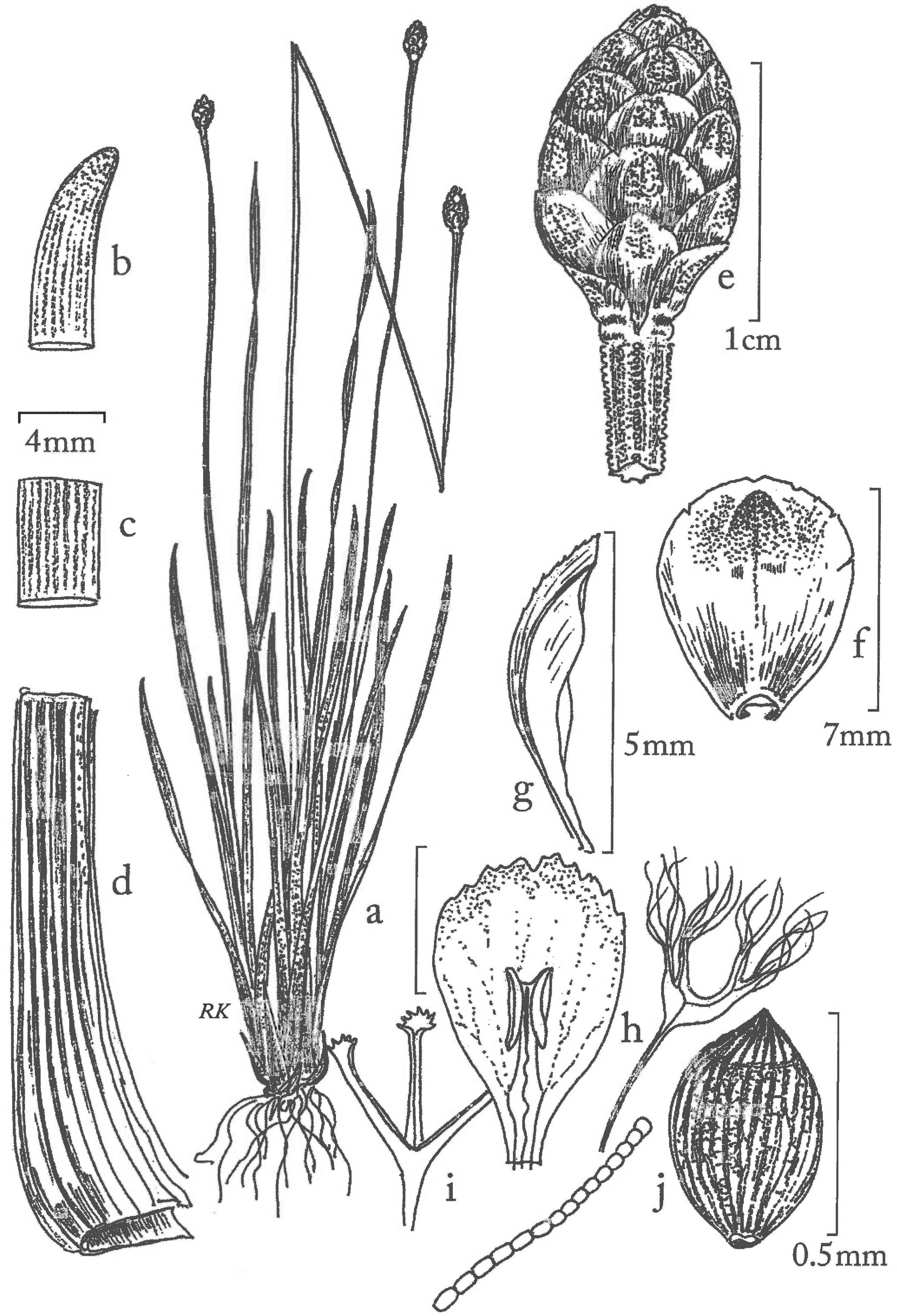

FIG. 3. *Xyris tennesseensis* (from *A. Schotz & L. Wyckoff 1546*). **a.** Habit sketch. **b.** Leaf tip. **c.** Sector of leaf midblade. **d.** Leaf sheath. **e.** Spike. **f.** Fertile bract. **g.** Lateral sepal. **h.** Petal blade, stamen (**left**); staminodium, enlarged view of beard hair (**right**). **i.** Stylar apex. **j.** Seed.

PARATYPE: ALABAMA. Bibb Co.: Alligator Glades West, small seep over Ketona Dolomite at headwaters of W branch of Alligator Creek (Lat 33° 04'; Long 87°, 01'), 7 Aug 1999, *R. Kral & M. Moffett 90103* (VDB).
Other specimens examined: ALABAMA. Bibb Co.: Alligator Glades West, small seep over Ketona Dolomite at headwaters of W branch of Alligator Creek (Lat 33° 04'; Long 87°, 01'), 5 Sep 1993, *James R. Allison* 7963 (AUA).

KEY TO *XYRIS TENNESSEENSIS* SYMPATRIC XYRIDS, INCL. *XYRIS DIFFORMIS* COMPLEX

1. Keel of laeral sepals usually firm, papilate, ciliate, ciliolate, or fimbriate, or in various combinations of these _____ **Xyris torta**
1. Keel of lateral sepals scarious, lacerate to (rarely) nearly entire.
   2. Leaf sheaths or sheath base light green, straw-colored, or dull brown _____ **Xyris jupicai**
   2. Leaf sheaths or sheath base with red, pink, or purple tints, or glossy brown or red-brown.
      3. Seeds opaque or mealy.
         4. Base of mature plant bulbous.
            5. Plant 30–70 cm in height; leaf sheaths and blade surfaces mostly smooth or just slightly papillate along keels and edges; scapes with 2 ridges somewhat flattened and wing-like distally, all papillate at edges; stem base lacks rhizomes _____ **Xyris tennesseensis**
            5. Plant 15–40 cm; leaf sheaths and blade surfaces papillate; scapes sharply 5–7 angled distally, ridges densely papillate-tuberculate; stem base possesses what may be short ascending rhizomes _____ **Xyris spathifolia**
         4. Base of mature plant not bulbous _____ **Xyris difformis** var. **floridana**
      3. Seeds translucent.
         6. Leaves and scapes (except for edges and ribs) smooth; scape somewhat to much widened distally; 2 ribs comparably wider, making wings smooth or papillate _____ **Xyris difformis** var. **difformis**
         6. Leaves and scapes variously papillate or minutely scabrous; scapes not much widened distally; ribs all equally prominent, somewhat scabrous _____ **Xyris difformis** var. **curtissii**

DISCUSSION

As mentioned in the prefatory paragraph, this plant, thus far known only from the type locality, was once abundant (over 200 clumps on the lower side of a small open seep). However, on our return to the site in August 2000, severe drought had drastically reduced numbers (thus eliminating the chance for additional voucher material). We hope to provide more vouchers once the population has recovered.

The question of what rank to assign this novelty is intriguing. Certainly, careful attention should be given to the plant at its sole known location, as well as searching for it in other calcareous fens of the area. Of particular interest is the fact that, prior to this discovery, only *Xyris tennesseensis* of North American xyrids was known to occupy fen-like habitats. One would be tempted to consider the new morphology a simple anomaly, perhaps a reaction to extreme habitat by *X. tennesseensis*, were it not for the side-by-side mixing of the two, which, nonetheless, are easily distinguished on the basis of several characters.

Differences in several character states between *X. spathifolia* and *X. tennesseensis* were manifest primarily in terms of leaf and scape surface features (i.e., ridges, wings, papillae), and the size of individual characters, as well as the overall plant. There was also a tendency for some *X. spathifolia* specimens to possess small lateral ascending offshoots reminiscent of rudimentary rhizomes, a feature not known from other North American xyrids. The differences exhibited by the new taxon are of a nature and degree that are consistent with species status distinctions recognized for this genus (Kral 1966; Kral 2000).

CONSERVATION CONSIDERATIONS

Considering the documented rarity of *X. spathifolia*, its association with and similarity to *X. tennesseensis*, and the specific threats associated with its single known extant site, a strong argument can be made for a "high" conservation ranking. This sole isolated site is located within a fire-suppressed loblolly pine plantation with severe woody tree/shrub encroachment. The overstocked plantings along (and within) the intermittent stream course supplying the fen are capable of drastically reducing groundwater levels (Jackson et al. 2005). Moreover, this site lacks formal legal protection (i.e., it is privately owned with no conservation easements/covenants in place). Thus it would seem to satisfy the requirements of both extreme rarity and

threat necessary to justify a critically imperiled ranking both globally and in Alabama (G1/S1), using the NatureServe (2008) system.

The rarity and threat to *X. spathifolia* would support its status as the xyrid of greatest conservation concern in North America (north of Mexico). The currently recognized *Xyris* species of greatest conservation concern is *X. tennesseensis*, known from approximately 25 sites in three states (AL, GA, and TN) with a NatureServe global ranking of imperiled (G2). *Xyris tennessensis* also has status and receives protection under the federal Endangered Species Act of 1973, under state law in Georgia through the Georgia Wildflower Preservation Act of 1973 (Georgia Dept. of Natural Resources 2008), and under state law in Tennessee through the Rare Plant Protection and Conservation Act of 1985 (Crabtree 2008). Conversely, as *X. spathifolia* is only now being recognized as a new species, it enjoys no legal protections at either the federal or state level. Further contributing to this precarious situation is the lack of any state laws protecting rare plants in Alabama.

The conservation situation involving *X. spathifolia* is obviously dire. Currently, there is some living material remaining from the common garden study that will be safeguarded at Georgia Plant Conservation Alliance (GPCA) member institutions and the Auburn University Donald E. Davis Arboretum. Visits to obtain additional *X. spathifolia* seed from the Alligator Glades West site, in order to bolster the existing *ex situ* collections, will be made in August/September of this year (2009). Efforts will also be made to work cooperatively with the new property owners of the Alligator Glades West site, Forest Investment Associates, to better manage the site for the benefit of both xyrids.

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